

V344 Lyr: an unusual large-amplitude SU UMa-type dwarf nova with a short supercycle

Taichi Kato¹, Gary Poyner², Timo Kinnunen³

¹ *Department of Astronomy, Faculty of Science, Kyoto University, Sakyo-ku, Kyoto 606-8502 Japan*

² *BAA Variable Star Section, 67 Ellerton Road, Kingstanding, Birmingham B44 0QE, England*

³ *Sinirinnantie 16, SF-02660 Espoo, Finland*

Accepted. Received; in original form

ABSTRACT

We studied the large-amplitude SU UMa-type dwarf nova V344 Lyr. A combination of our observations and reports to VSNET has yielded an extensive coverage of outbursts between 1994 July and 2001 June. The analysis of this data showed a mean supercycle length of 109.6 d. This value is one of the smallest among known SU UMa-type dwarf novae (except unusual ER UMa-type dwarf novae). The outburst amplitude of V344 Lyr (~ 5.5 mag) is found to be much larger than those (3.5 ± 0.3 mag) of SU UMa-type dwarf novae with similar supercycle lengths. Such a deviation of the amplitude in V344 Lyr is difficult to explain by the inclination effect. The extreme outburst parameters of V344 Lyr would require an additional mechanism to effectively reduce the quiescent luminosity or to increase the outburst frequency.

Key words: accretion: accretion disks — stars: cataclysmic — stars: dwarf novae — stars: individual (V344 Lyr)

1 INTRODUCTION

Dwarf novae are a class of cataclysmic variables (CVs), which are close binary systems consisting of a white dwarf and a red dwarf secondary transferring matter via the Roche lobe overflow. Thermal instability in the resultant accretion disk is now widely believed to cause dwarf nova-type outbursts (see Osaki (1996) for a review). In dwarf novae whose binary mass-ratios ($q=M_2/M_1$) are small enough, a different kind of instability – tidal instability – occurs (Whitehurst 1988), which is now widely believed to be a cause of superoutburst and superhumps in SU UMa-type dwarf novae (for a recent review of SU UMa-type stars and their observational properties, see Warner (1995)).

Among SU UMa-type dwarf novae, some objects show large-amplitude outbursts. Although there is evidence that outburst amplitudes of dwarf novae are known to comprise a continuum from small to large amplitudes (see a discussion in Patterson et al. 1996), these large-amplitude objects are sometimes symbolically known as TOADs (Tremendous Outburst Amplitude Dwarf Novae: Howell et al. 1995). At the extreme end, there exist so-called WZ Sge-type dwarf novae (originally proposed by Bailey (1979); see also Downes & Margon (1981) and O’Donoghue et al. (1991)). WZ Sge-type dwarf novae (and related systems) are known to show peculiar outburst characteristics among SU UMa-type dwarf novae: 1) long interval between outbursts (WZ Sge itself has a recurrence time of 23 to 33 yr, which is the longest among all

known dwarf novae), 2) lack or very low frequency of normal outbursts, which are more abundant than superoutbursts in usual SU UMa-type dwarf novae (no normal outburst has ever been observed in WZ Sge itself) and 3) extremely long (up to ~ 100 d) and bright superoutbursts.

V344 Lyr is a dwarf nova discovered by Hoffmeister (1966). Kato (1993) detected superhumps with a period of 0.09145(2) d, which confirms that V344 Lyr is a member of SU UMa-type dwarf novae with long orbital periods. The reported range of variability (13.8 – [20 V) makes V344 Lyr a candidate for rare large-amplitude dwarf novae with long orbital periods. Since many of large-amplitude SU UMa-type dwarf novae are known to be most infrequently outbursting systems, the proposed supercycle of 240 d (Kato 1993) would make V344 Lyr an exceptional object. In order to clarify the situation, we examined our observations and the observations between 1994 July and 2001 June, made by the VSNET Collaboration ¹.

2 OBSERVATIONS AND RESULTS

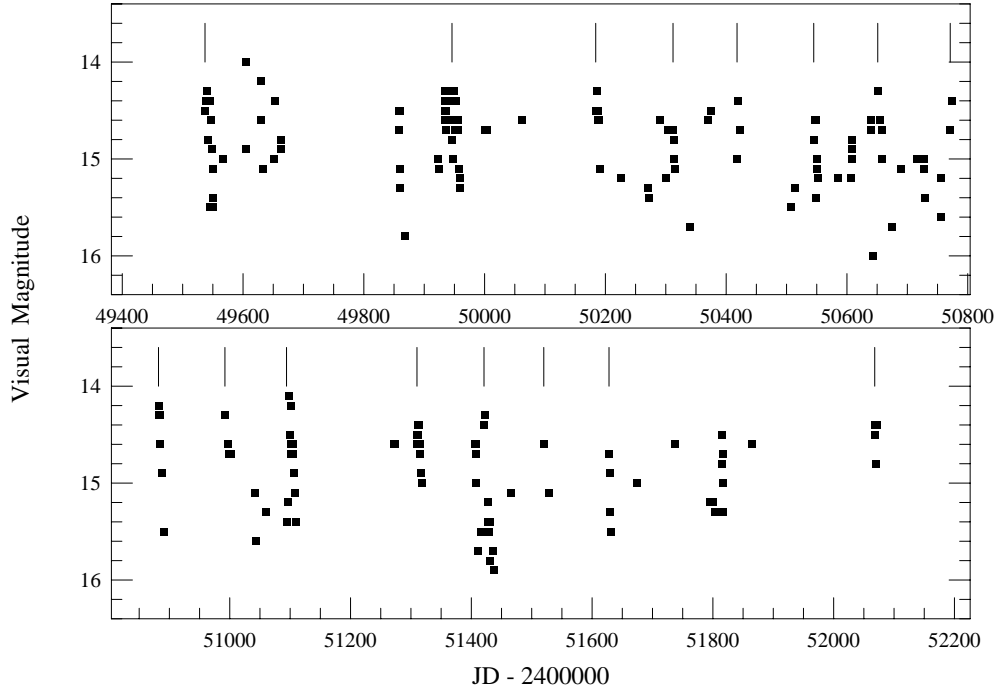
2.1 Outburst cycle length and statistics

The observations by the authors and those from VSNET were made visually, using V -magnitude calibrated compari-

¹ <http://www.kusastro.kyoto-u.ac.jp/vsnet/>

Table 1. Outbursts of V344 Lyr

JD start	peak mag	length (d)	type	JD start	peak mag	length (d)	type
2449537	14.4	13	super	2450651	14.3	>8	super
2449566	15.0	1	normal	2450674	15.7	1 ^a	normal
2449604	14.0	2	normal	2450689	15.1	1 ^a	normal
2449629	14.2	4	normal	2450716	15.0	1 ^a	normal
2449651	14.4	3	normal	2450727	15.0	3	normal
2449662	14.8	2	normal	2450755	15.2	2	normal
2449857	14.5	4	normal	2450771	14.4	>4	super?
2449867	15.8	1 ^a	normal	2450882	14.2	>9	super
2449923	15.0	2	normal	2450992	14.3	10	super
2449934	14.3	2	normal	2451042	14.7	2	normal
2449946	14.3	13	super	2451060	15.3	1 ^a	normal
2450001	14.6	3	normal	2451094	14.2	16	super
2450062	14.6	1 ^a	normal	2451271	14.6	3	normal
2450184	14.3	>7	super	2451310	14.4	>8	super
2450225	15.2	1 ^a	normal	2451406	14.6	3	normal
2450270	15.3	2	normal	2451416	15.5	1 ^a	normal
2450290	14.6	2	normal	2451421	14.3	16	super
2450300	14.7	3	normal	2451465	15.1	1 ^a	normal
2450312	14.7	>3	super?	2451520	14.6	>8	super
2450340	15.7	1 ^a	normal	2451628	14.7	>3	super?
2450370	14.6	4	normal	2451674	15.0	1 ^a	normal
2450418	14.4	>4	super?	2451737	14.6	1 ^a	normal
2450506	15.5	1 ^a	normal	2451795	15.2	1 ^a	normal
2450514	15.3	1 ^a	normal	2451800	15.2	4	normal?
2450545	14.6	>6	super?	2451815	14.5	2	normal?
2450585	15.2	1 ^a	normal	2451865	14.6	1 ^a	normal
2450607	14.9	2	normal	2452068	14.4	>4	super
2450639	14.6	4	normal				

^a Single observation.^b Double peaks.**Figure 1.** Overall light curve of V344 Lyr. Superoutbursts are marked with ticks. Upper-limit observations are not plotted for simplicity.

son stars. The typical error of visual estimates was 0.2 mag, which will not affect the following discussion. The total number of observations was 1089. The number of positive observations was 209, corresponding to the outburst duty cycle of 19%. Although this value may have suffered from some degree of selection bias, the large duty cycle is already unusual for a system with a large outburst amplitude. We selected outbursts from these data, which are summarized in Table 1 and Figure 1.

Most outbursts were unambiguously classified as either normal outbursts or superoutbursts based on their duration and peak magnitudes, but the faintness of the object and sometimes unfavourable observing conditions made some of classifications slightly ambiguous. Such outbursts are flagged as “?”.

2.2 Outburst amplitude

Since the outburst amplitude is sensitive to outburst and quiescent magnitudes, we have tried to recalibrate these values using the modern V scale. Since recent outburst observations have been made using modern V -magnitude comparison stars, we have adopted $V=14.0$ as the maximum magnitude. [This value is in agreement with the $V=14.2$ obtained by Kato (1993). Even a better agreement would be achieved when considering that the CCD observation by Kato (1993) started a few days after the visual maximum.]

Regarding the quiescent magnitude, Hoffmeister (1966) stated that “the object is invisible on the Palomar Sky Survey plates”, from which an upper limit of 20 has been adopted in the literature. We have confirmed this finding by a direct inspection of paper reproductions of the POSS I plates. The object is also missing from the USNO A1.0 and A2.0 catalogs, which reach a limiting magnitude of 19.5. We have also found that the object is faintly seen on the digitized POSS I plates, available at the USNOFS Image and Catalogue Archive, and yielded a magnitude of $R=19.5\pm0.3$, by comparison with the modern comparison stars. Since short-period dwarf novae have colors close to $V-R=0$ even in quiescence, this value is considered to be a good approximation of the quiescent V magnitude.

We have also inspected the available images, on which V344 Lyr was probably recorded at or close to its minimum (the object was recorded in outburst on POSS II plates). The images taken at Ouda Station, Kyoto University (Ohtani et al. 1992), on 1991 February 23 have yielded $I_c=17.8\pm0.2$. An unfiltered CCD image on 1996 July 17 shows no hint of the object down to 19.0 mag. The Guide Star Catalog plates, as given in Downes & Shara (1993), show the object at 18–19 mag. The above results are summarized in Table 2. These results may suggest a considerable variation of the quiescent magnitude, but it would not be surprising that the object may not have completely reached quiescence in some observations, when one takes the large outburst duty cycle of 19 % into account. From these observations, we adopted 5.5 ± 0.3 mag for the outburst amplitude of V344 Lyr.

Table 2. Quiescent magnitudes of V344 Lyr.

Source	Year	Magnitude	Band
DSS 1	1955.555	19.5 ± 0.3	POSS red
GSC plate scan	1982.390	18–19	V
This study	1991.147	17.8 ± 0.2	I_c
This study	1996.543	[19.0	unfiltered CCD ^a

^a System close to R_c .

3.1 Length of supercycle

The most prominent sequence of superoutbursts can be found between JD 2450882 and 2451094 (Figure 2). The detection of three successive superoutbursts establishes the supercycle of ~ 110 d, which is half of the estimate by Kato (1993). The other superoutbursts and candidate superoutbursts are well expressed by this period, but the supercycle does not seem to be extremely stable: the supercycle seems to be longer (~ 120 – 130 d) in 1994–1995. Using the best sampled interval (JD 2450312 – 2451628), a regression of the observed epochs of superoutbursts yielded a supercycle of 109.6 d. This supercycle length is one of the shortest among known SU UMa-type dwarf novae (cf. Nogami et al. 1997), except ER UMa stars (Kato & Kunjaya 1995; Robertson et al. 1995; Misselt & Shafter 1995; Nogami et al. 1995) which are unusual SU UMa-type dwarf novae with an exceptionally large outburst frequency (supercycle lengths are shorter than 60 d; normal outbursts occur every 3–5 d) and a small outburst amplitude (for an observational review and theoretical explanations of ER UMa stars, see Kato et al. 1999 and Osaki 1995, respectively).

3.2 Outburst amplitude versus supercycle length

As shown in Section 3.1, the supercycle of V344 Lyr is 109.6 d, which is exceptionally short for an SU UMa-type dwarf nova with a large outburst amplitude. Table 3 lists the properties of SU UMa-type dwarf novae with well-established short supercycle lengths ($T_s < 300$ d)². The source data are from Nogami et al. (1997), with recent revisions and additions mentioned in the individual notes. Excluding SX LMi (unusual low-amplitude system as discussed by Nogami et al. (1997)), Z Cha (high-inclination eclipsing system) at lower right, and V344 Lyr, we found the following good correlation between T_s and outburst amplitude (A) for systems $T_s > 80$ d (i.e. normal SU UMa stars).

$$A = 2.04 \log(T_s) - 0.4. \quad (1)$$

Most remarkable is that the outburst amplitudes of SU UMa-type dwarf novae are confined to a narrow range (3.1 to 4.0 mag) for systems between $T_s=84$ and $T_s=174$, except V344 Lyr. This distribution has a mean amplitude of 3.5 mag and a standard deviation of 0.3 mag. The observed

² The limit has been chosen for two reasons: (1) T_s tends to be stable in frequently outbursting systems (i.e. short T_s systems), the extreme cases being ER UMa stars. Systems with superoutbursts less than once per year often do not have a fixed T_s . (2) Due to unavoidable seasonal observational gaps, long T_s systems have uncertainties in unambiguously identifying T_s .

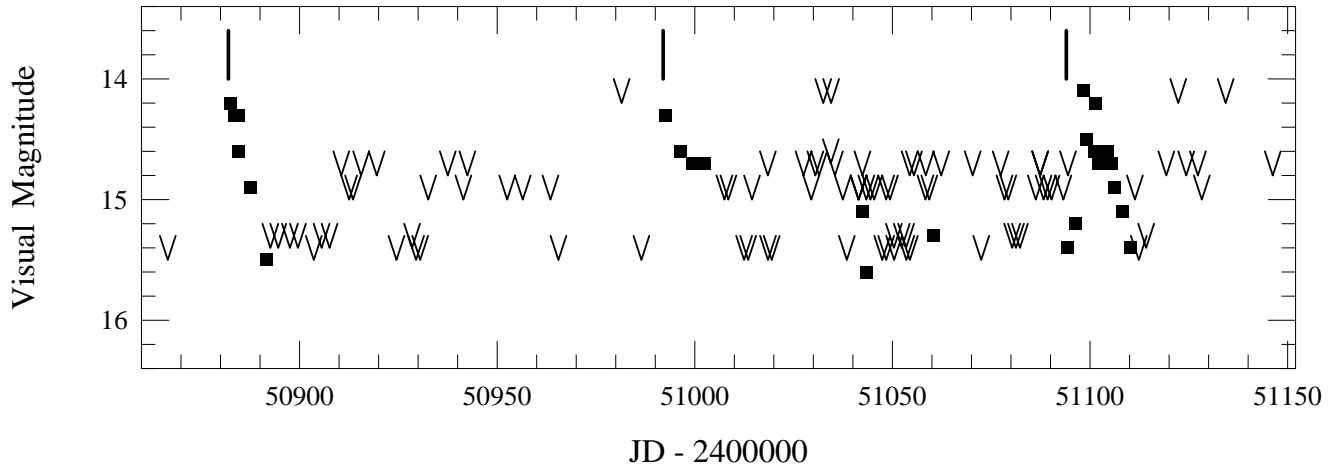


Figure 2. The light curve of V344 Lyr between JD 2450860 (1998 February 16) and JD 2451152 (1998 December 5). The “v” marks represent upper-limit observations. The durations and brightness of the marked outbursts qualify them as superoutbursts, confirming the short supercycle of ~ 110 d. Note that the marks on the superoutbursts correspond to the earliest detection of each superoutburst. The third superoutburst was detected during its rise to maximum. Two short, fainter outbursts (normal outbursts) occurring on JD 2451042 and 2451060 were detected between the second and third superoutbursts.

Table 3. Properties of SU UMa-type dwarf novae with short supercycles.

Name	P_{SH} (d)	Max	Min	Amp ^a	T_s^b (d)
RZ LMi	0.05946	14.2	17.0	2.8	19
DI UMa	0.0555	15.1	18.0	2.9	25
ER UMa	0.06573	12.9	15.8	2.9	43
V1159 Ori	0.06861	12.8	15.4	2.6	44.6–53.3
IX Dra	0.06700	15.0	17.5	2.5	45.7–53
SS UMi	0.0699	13.6	16.7	3.1	84.7
NY Ser	0.1064	14.53	18.2	3.7	70–100
V503 Cyg	0.08101	13.95	17.5	3.5	89
V344 Lyr	0.09145	14.0	19.5	5.5	109.6
FO And	0.07411	13.9	17.5	3.6	100–140
YZ Cnc	0.09204	11.0	15.0	4.0	134
V1504 Cyg	0.0690	13.8	17.4	3.6	137
VZ Pyx	0.07576	11.8	15.2	3.4	152
SU UMa	0.0788	11.3	15.0	3.7	160
WX Hyi	0.07737	11.4	14.9	3.5	174
VW Hyi	0.07714	8.7	13.8	5.1	179
IR Gem	0.07094	11.4	16.3	4.9	183
V1113 Cyg	0.0792	13.6	18.6	5.0	189.8
TY PsA	0.08765	11.8	15.9	4.1	202
AY Lyr	0.0756	12.4	18.4	6.0	210
TT Boo	0.07811	12.7	19.2	6.5	245
RZ Sge	0.07042	12.2	17.4	5.2	266
SX LMi	0.06850	13.3	16.8	3.4	279
Z Cha	0.07740	12.7	15.6	2.9	287

^a Amplitude (mag).

^b Length of supercycle.

amplitude of V344 Lyr (5.5 ± 0.3 mag) is $7 \pm 1\sigma$ larger than the average. Even adopting a conservative upper limit of the minimum magnitude of 18.5 (from GSC plate scan), the value is still 3σ above the average.

Warner (1987) presented, with an assumption of an optically thick disk, a formulation of the dependence of the absolute V magnitude on the system inclination. A disk seen at nearly edge-on ($i=85^\circ$) is 3.5 mag brighter than the pole-

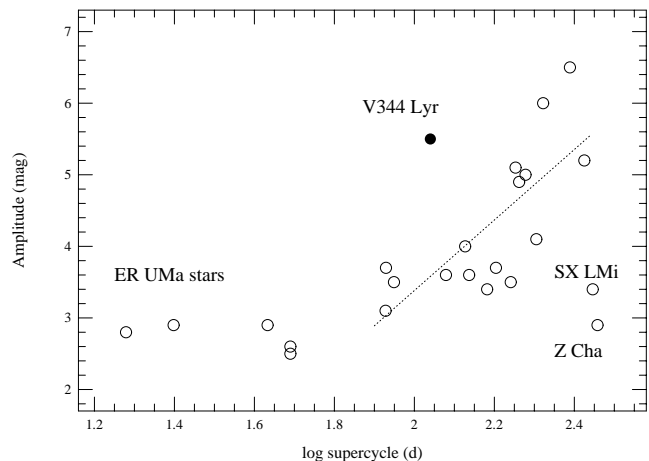


Figure 3. Log T_s versus outburst amplitudes drawn from Table 3. There is a tight relation between T_s and outburst amplitudes. The dotted line represents Eq. 1. Two systems at significantly below this line include SX LMi and Z Cha, a unusual low-amplitude system and a high-inclination eclipsing system, respectively. The deviation of V344 Lyr above this line is evident.

on ($i=0^\circ$) view. Although this inclination effect explains the existence of low-amplitude systems among eclipsing systems (e.g. Z Cha), it would be difficult to explain the existence of high-amplitude systems, since a pole-on disk is expected to be only 0.4 mag brighter than systems with moderate inclinations (Warner 1987). Such a large outburst amplitude as in V344 Lyr would thus be difficult to reproduce simply by the geometrical effect. Since superoutbursts of V344 Lyr have quite typical properties of usual SU UMa-type dwarf novae (Kato 1993), it is unlikely the superoutbursts of V344 Lyr are intrinsically brighter, which implies that the quiescent accretion disk of V344 Lyr is fainter than the average.

The standard disk instability theory expects that the quiescent luminosity is a strong function of the mass-transfer rate and the quiescent viscosity (cf. Warner 1987; Smak 1989; Cannizzo 1998). Since the same theory expects that

the supercycle length is inversely proportional to the mass-transfer rate (Ichikawa & Osaki 1994), the mass-transfer rate in V344 Lyr is expected to be higher than the average, which would work to reduce the outburst amplitude. The modification of the quiescent viscosity could be a viable idea, but is against the observed high frequency of normal outbursts. V344 Lyr thus shows a considerable departure from known SU UMa-type systems, and may require an additional mechanism to effectively reduce the quiescent luminosity or to increase the outburst frequency. Further detailed observations of V344 Lyr, especially orbital parameters and long-term quiescent photometry are therefore necessary.

Notes on individual objects in Table 3:

DI UMa – Large change of T_s has been inferred (Fried et al. 1999). The value given in the table corresponds to the most stable outbursting period (Kato et al. 1996; Kato et al. in preparation).

V1159 Ori – Newly determined T_s from Kato (2001a).

IX Dra – Newly discovered ER UMa-type dwarf nova. The data are from Ishioka et al. (2001).

SS UMi – T_s from Kato et al. (2000). The maximum magnitude of $V=12.6$ (Mason et al. 1982) was probably in error; no such bright outburst has been observed in plate searches (see also Richter 1989; Kato et al. 1998). The maximum magnitude is taken from the recent VSNET observations.

FO And – T_s and maximum magnitude have been revised using VSNET observations.

VZ Pyx – T_s listed in Kato & Nogami (1997) and Nogami et al. (1997) was erroneous. The new T_s is determined from VSNET observations, which show very regular supercycles, resembling those of YZ Cnc. The maximum and minimum magnitudes are also from VSNET observations, based on the newly calibrated V -magnitude sequence.

SU UMa – Typical T_s is given. The system sometimes shows reduced outburst and superoutburst frequencies (Rosenzweig et al. 2000).

WX Hyi – Typical T_s , as measured from VSNET observations between 1996 and 1998, is given. The system is known to sometimes show a reduced frequency of superoutbursts.

VW Hyi – Revised maximum and minimum magnitudes from VSNET observations.

IR Gem – Revised T_s based on the analysis of the VSOLJ data. Revised superhump period from Kato (2001b). The maximum and minimum magnitudes are from VSNET observations and citetmis96sequence, respectively.

V1113 Cyg – Mean T_s from Kato (2001c), which reported a variation of supercycles between 169 and 229 d. Kato (2001c) reported rather unusual outburst characteristics, having a low ratio of (normal outbursts)/(superoutbursts). The minimum magnitude given is our new calibration of the DSS 1, while Liu et al. (1999) reported a rough estimate of $V=20.8$ from their spectroscopic observation. The system requires further detailed study in quiescence.

TY PsA – Revised T_s and maximum magnitude from VSNET observations.

AY Lyr – Revised T_s and maximum magnitude from VSNET observations. The minimum magnitude is taken from Misselt (1996).

SX LMi – Mean T_s from Kato (2001d), which showed a variation of supercycles between 250 and 312 d.

The following objects in Nogami et al. (1997) have been excluded from the list:

CI UMa – Nogami & Kato (1997) listed a possible supercycle of 140 d, while recent reports to VSNET show that the intervals are typically longer and outbursts occur rather irregularly (see also Kato et al. (2000)).

V630 Cyg – Nogami et al. (1997) listed a possible supercycle of 290 d. Recent study by Nogami et al. (2001) indicates that supercycles vary more irregularly.

4 SUMMARY

We observed the large-amplitude SU UMa-type dwarf nova V344 Lyr. Combined with reports to VSNET, we have succeeded in determining its mean supercycle length as 109.6 d. This value is one of the smallest among known SU UMa-type dwarf novae (except unusual ER UMa-type dwarf novae). The observed outburst amplitude (5.5 ± 0.3 mag) in V344 Lyr is found to be exceptionally large for a system with such a short supercycle. Since a short supercycle strongly suggests a relatively high mass-transfer rate, the extreme outburst parameters of V344 Lyr would require a mechanism to effectively reduce the quiescent luminosity or to increase the outburst frequency.

ACKNOWLEDGMENTS

The authors are grateful to VSNET members, especially to L. Szentasko, T. Vanmunster, J. Pietz, L. T. Jensen, E. Broens, M. Reszelski for providing vital observations. The authors are grateful to the staff of the VSOLJ (Variable Star Observers League) for their on-line database. We are also grateful to an anonymous referee, whose comments significantly improved the paper. This research has made use of the USNOFS Image and Catalogue Archive operated by the United States Naval Observatory, Flagstaff Station (<http://www.nofs.navy.mil/data/fchpix/>).

REFERENCES

- Bailey J., 1979, MNRAS, 189, 41P
- Cannizzo J. K., 1998, ApJ, 493, 426
- Downes R. A., Margon B., 1981, MNRAS, 197, 35P
- Downes R. A., Shara M. M., 1993, PASP, 105, 127
- Fried R. E., Kemp J., Patterson J., Skillman D. R., Retter A., Leibowitz E., Pavlenko E., 1999, PASP, 111, 1275
- Hoffmeister C., 1966, Astron. Nachr., 289, 139
- Howell S. B., Szkody P., Cannizzo J. K., 1995, ApJ, 439, 337
- Ichikawa S., Osaki Y., 1994, in Duschl W. J., Frank J., Meyer F., Meyer-Hofmeister E., Tscharnuter W. M., eds, Theory of Accretion Disks-2 Kluwer Academic Publishers, Dordrecht, p. 169
- Ishioka R., Kato T., Uemura M., Iwamatsu H., Matsumoto K., Martin B., Billings G. W., Novák R., 2001, PASJ, in press
- Kato T., 1993, PASJ, 45, L67
- Kato T., 2001a, PASJ, 53, L17
- Kato T., 2001b, Inf. Bull. Var. Stars, 5122

- Kato T., 2001c, *Inf. Bull. Var. Stars*, 5110
- Kato T., 2001d, *Inf. Bull. Var. Stars*, 5071
- Kato T., Hanson G., Poyner G., Muyliaert E., Reszelski M., Dubovsky P. A., 2000, *Inf. Bull. Var. Stars*, 4932
- Kato T., Kunjaya C., 1995, *PASJ*, 47, 163
- Kato T., Lipkin Y., Retter A., Leibowitz E., 1998, *Inf. Bull. Var. Stars*, 4602
- Kato T., Nogami D., 1997, *PASJ*, 49, 481
- Kato T., Nogami D., Baba H., 1996, *PASJ*, 48, L93
- Kato T., Nogami D., Baba H., Masuda S., Matsumoto K., Kunjaya C., 1999, in Mineshige S., Wheeler J. C., eds, *Disk Instabilities in Close Binary Systems Universal Academy Press, Tokyo*, p. 45
- Liu W., Hu J. Y., Zhu X. H., Li Z. Y., 1999, *ApJS*, 122, 243
- Mason K. O., Reichert G. A., Bowyer S., Thorstensen J. R., 1982, *PASP*, 94, 521
- Misselt K. A., 1996, *PASP*, 108, 146
- Misselt K. A., Shafter A. W., 1995, *AJ*, 109, 1757
- Nogami D., Buczynski D., Baba H., Kato T., 2001, *Inf. Bull. Var. Stars*, 5157
- Nogami D., Kato T., 1997, *PASJ*, 49, 109
- Nogami D., Kato T., Masuda S., Hirata R., Matsumoto K., Tanabe K., Yokoo T., 1995, *PASJ*, 47, 897
- Nogami D., Masuda S., Kato T., 1997, *PASP*, 109, 1114
- O'Donoghue D., Chen A., Marang F., Mittaz J. P. D., Winkler H., Warner B., 1991, *MNRAS*, 250, 363
- Ohtani H., Uesugi A., Tomita Y., Yoshida M., Kosugi G., Noumaru J., Araya S., Ohta K., 1992, *Memoirs of the Faculty of Science, Kyoto University, Series A of Physics, Astrophysics, Geophysics and Chemistry*, 38, 167
- Osaki Y., 1995, *PASJ*, 47, L11
- Osaki Y., 1996, *PASP*, 108, 39
- Patterson J., Augusteijn T., Harvey D. A., Skillman D. R., Abbott T. M. C., Thorstensen J., 1996, *PASP*, 108, 748
- Richter G. A., 1989, *Astron. Nachr.*, 310, 143
- Robertson J. W., Honeycutt R. K., Turner G. W., 1995, *PASP*, 107, 443
- Rosenzweig P., Mattei J., Kafka S., Turner G. W., Honeycutt R. K., 2000, *PASP*, 112, 632
- Smak J., 1989, *Acta Astron.*, 39, 317
- Warner B., 1987, *MNRAS*, 227, 23
- Warner B., 1995, *Ap&SS*, 226, 187
- Whitehurst R., 1988, *MNRAS*, 232, 35